



SOCIAL SCIENCE

Madrid cycle track: visualizing the cyclable city

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ABSTRACT

Maps are currently experiencing a paradigm shift from static representations to dynamic platforms that capture, visualize and analyse new data, bringing different possibilities for exploration and research. The first objective of this paper is to present a map that illustrates, for the first time, the real flow of casual cyclists and bike messengers in the city of Madrid. The second objective is to describe the development and results of the *Madrid Cycle Track* initiative, an online platform launched with the aim of collecting cycling routes and other information from volunteers. In the framework of this initiative, different online maps are presented and their functionalities described. Finally, a supplemental video visualizes the cyclist flow over the course of a day.

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1. Introduction

The understanding of urban cyclist behaviour is crucial to planning and designing optimal bike infrastructures and promoting efficient policies aimed at fostering cycling as a sustainable mode of transport in cities. Cyclist behaviour is complex and not easily predictable because it is influenced by a diverse set of factors. With different objectives, it has been traditionally analysed through the information derived from household surveys or more specific group surveys. Regarding the areas of demand analysis, preference evaluation and forecasting, Stated Preference (SP) techniques have been commonly applied (e.g. Kroes and Sheldon (1988)), in order to measure the effects of certain improvement on cycle facilities and then forecast the effect of others (Hopkinson & Wardman, 1996) or with the aim of estimating the potential cycle demand in certain urban areas (Ortúzar, Iacobelli, & Valeze, 2000). Also, Revealed Preference (RP) studies have been conducted with different purposes, such as the development of mode choice models (Noland & Kunreuther, 1995).

More specifically, concerning the spatial analysis of cycling for planning purposes, SP and RP methods have been the dominant techniques. In SP studies, respondents were typically asked to evaluate the impact of different factors on their cycle route choice, or to state their preference for a street or a route by evaluating the options using photos of the routes or locations (Bradley & Bovy, 1984; Larsen & El-Geneidy, 2011; Tilahun, Levinson, & Krizek, 2007). Some RP-based studies asked respondents to design their cycle route on a map (Ben-aiuva & Morikawa, 1990) and finally,

some approaches involved both SP and RP techniques, but still using similar methods (Yang & Mesbah, 2013).

In recent years, the research on cycling has grown substantially, and shifted with the emergence of new location-based data allowing more complex spatial analysis. Recent investigations have studied two different types of location data: point data captured by the growing Bike-Share Systems spread around the world (Côme & Latifa, 2012; Froehlich, Neumann, & Oliver, 2009; O'Brien, Cheshire, & Batty, 2013; Zaltz Austwick, O'Brien, Strano, & Viana, 2013) and GPS tracking data collected through smartphones applications or specific devices, gathered specifically with research purposes or made available by 'Big App' Companies for research or planning (Broach, Dill, & Gliebe, 2011; Harvey & Krizek, 2007; Menghini, Carrasco, Axhausen, & Schüssler, 2010).

By overcoming the traditional SP and RP limitations in terms of high costs, small samples and spatial imprecision (Hood, Sall, & Charlton, 2011), these new studies are improving the understanding of urban cyclist behaviour and producing outputs to inform the planning and design of bike infrastructures and policies.

The goal of this paper is to describe the objectives, the methodology and the outputs of the initiative *Huella Ciclista de Madrid* (Madrid Cycle Track), launched with the aim of collecting cycling routes and other information from volunteers in the city of Madrid, as well as to present the resulting map – and its online version – that represents all the gathered cyclist routes. Finally, the paper also visualizes the cyclist flow over the course of a day through a supplemental video.

Urban cycling in Spain has one of the lowest rates in the European Union (Roldán, Díaz, & Mellado, 2013)

and Madrid has a particularly low modal split (0.6% according to Ayuntamiento de Madrid (2013)) compared to other cities such as Barcelona or Seville (2.0% and 6.6%, respectively, according to Agencia de Ecología Urbana de Barcelona (2014)). However, the number of cyclists in the city has grown significantly in recent years, and the municipality has launched a series of initiatives, ranging from a bike-share system to a new cycling infrastructure, with the objective of reaching 4.5% of the modal split in 2020 (Ayuntamiento de Madrid, 2014). Specific geographical characteristics that shape the observed patterns of cycling (topography and land-use distribution, e.g.) are discussed in the results section.

2. The initiative Madrid cycle track

2.1. Background and main objectives

Madrid Cycle Track (originally *Huella Ciclista de Madrid*, in Spanish) launched in June 2013 in the framework of a broader research aimed at developing new models for designing optimal bike networks, in which the understanding of cyclist behaviour and route preferences plays a crucial role. In this domain, modelling is targeted to forecast the potential cyclist flow in different bike network proposals, evaluating the impact of different factors on cyclists' route choice (such as the slope of the streets, the type of bikeway or traffic density) as well as disaggregating cyclists by factors such as age or gender or journey purpose. In order to perform this evaluation, an analysis of real cyclist routes in Madrid (the research case study) was required.

The available information on Madrid bike mobility was limited to the Transport Household Survey conducted in 2004 and other more specific surveys aimed at analysing the evolution of cycling in certain areas of the city in which bike infrastructure has been implemented. Because these surveys did not provide relevant spatial data for the purpose of the investigation, the research team conceived the initiative *Madrid Cycle Track* with the aim of gathering cyclist routes and other relevant data from volunteers in the city of Madrid.

2.2. The online platform and the participation process

The initiative was launched through an online platform (website available at www.huellaciclistademadrid.es), designed with five different objectives. The first one was to provide information about the project's background and goals, so that potential volunteers could get interested in it. The second goal was to enable the engagement of urban cyclist interested in the initiative. Volunteers could register, download a free GPS smartphone application, Map My Tracks, and join the group

of volunteers within the online platform to make the process minimize the risk of volunteer dropout.

The third and main objective of the online platform was to collect cyclists' routes. Volunteers could upload the routes to the platform in three different ways. Initially, a cyclist could only participate by uploading routes through the smartphone GPS app. All of the data were stored in the app website and then downloaded by the research team. In a second stage of the project, due to volunteer demand, the gathering process let the cyclists to upload GPS that they collected through other GPS apps. The number of cyclists participating through this option was not very high, but was easily implemented and provided some extra GPS tracks. Finally, in order to open the initiative to people not owning a smartphone or not willing to use the app for whatever reason, a participative online map was embedded on the platform enabling volunteers to easily design their cycle routes on a map with accuracy and with the possibility of providing some extra information about themselves (such as age and gender) and their routes (such as purpose and frequency of the journey or safety of the route).

The fourth goal was to let cyclists visualize their routes, get access to different statistics and explore some data about their activity (distance and time travelled, gradient, slope, speed, etc.). Volunteers could also look up other group members' activity and get in touch with them by text messages. These functionalities provided the sense of belonging to a community, and encourage people to participate and to invite other people to join the initiative. Figure 1 shows a screenshot of the online platform illustrating collected cyclists' routes.

Finally, the fifth objective of the online platform was to visualize the *collective cycle track* through different online maps that represented the evolution and the growth of the track over time. The representation of all the routes together through online maps let the possibility of exploring the city, visualizing the streets with highest levels of cyclist flow according, for example, or relating routes to journey purpose. However, providing appealing feedback to the volunteers who altruistically participated in the initiative was a goal in itself. They could not only visualize the collective track, but also identify and look up individual contributions by clicking on the routes. These online maps are described in more detail in later sections.

2.3. Bike messengers engagement

Bike messengers companies are experiencing a renaissance, playing a growing role in the delivery of packages and mail in many major cities (Fleming, 2012; Hong, Zhiliang, & Wei, 2006; Kidder, 2008). Cycle couriership is not only a competitive transport mode for the delivery of time-sensitive materials in

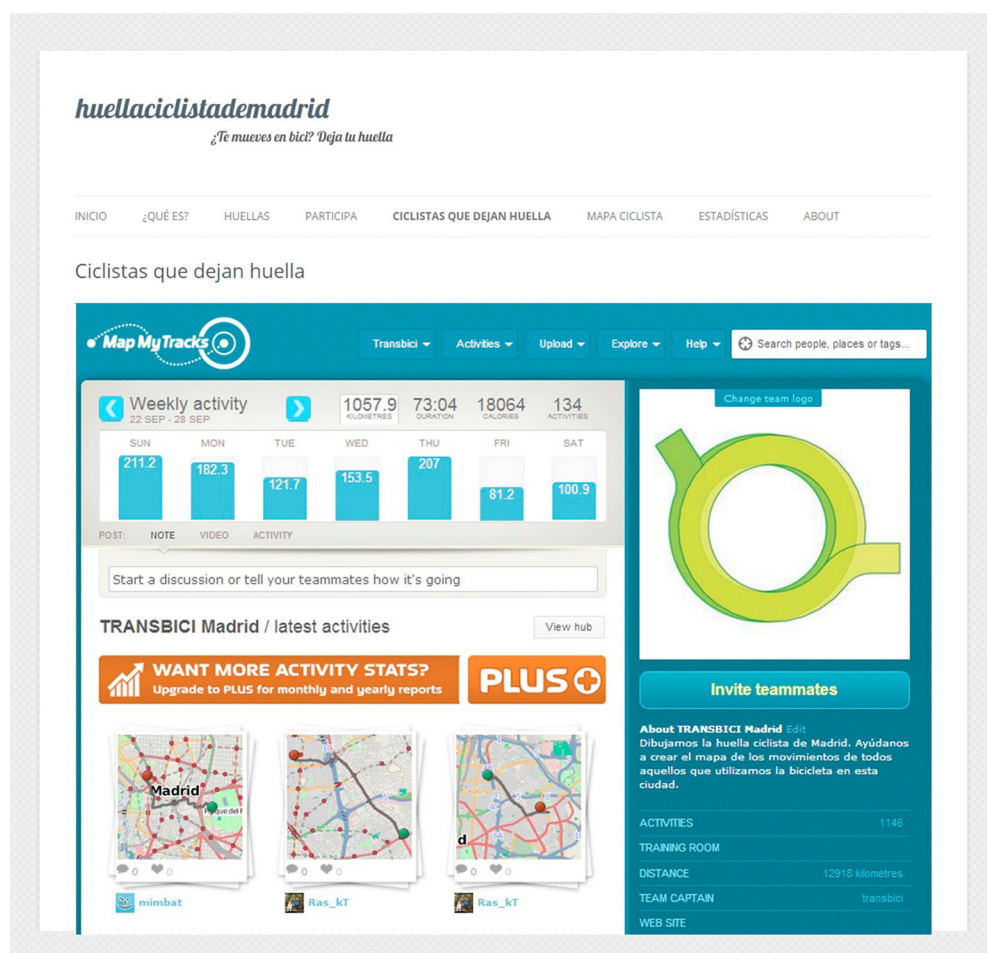


Figure 1. Screenshot of the online platform illustrating collected cyclists' routes.

the core of many metropolitan areas (Kidder, 2008, 2011), but is also attractive from a sustainability perspective. Many cities are implementing policies aimed at fostering this sustainable transport system in urban areas (Fleming, 2012; Hong et al., 2006). In this sense, the study of bike messengers' mobility could provide some relevant clues for better implementing these planning and policy strategies. However, while bike messengers have been studied from the social research field (Fincham, 2007; Kidder, 2011) or regarding environmental questions (Bernmark, Wiktorin, Svartengren, Lewné, & Aberg, 2006), their mobility is underexplored and has not been spatially analysed (with few exceptions; for example, Kidder (2008)), in comparison with casual cyclists or other transport modes.

The city of Madrid is not an exception and several new bike messengers companies emerged recently. Our interest for studying and comparing their mobility patterns with one of the casual bikers for which we had started collecting data led us to open the Madrid Cycle Track initiative to their participation. On November 2013, four different companies based in Madrid joined the initiative and started to track their activity: *Emakers*, *Trébol ecomensajeros*, *Mensos* and *BikePost ecomensajeros*.

Though the bike messengers' activity was eventually integrated in the existing online platform, the methodology followed to collect their routes differed from the one followed with casual bikers. Since couriers cycle many hours a day and often use their phones for working purposes, smartphone GPS apps have serious issues around battery life. Instead, these companies were equipped with specific cycling GPS devices (Garmin EDE 200). Their tracks were initially uploaded to a Garmin online platform (Garmin Connect), and then downloaded and integrated in the online platform of Madrid Cycle Track, where they were visualized through an independent online map, similar to the one displaying casual bike mobility.

2.4. Results

A total of 6022 cycle routes were gathered, resulting in 48,122 km of tracks uploaded by 328 volunteers participating from June 2013 to September 2014, taking into account both the casual cyclists and bike messengers.

2.4.1. Casual cyclists results

Casual cyclists' routes were mainly collected from June 2013 to March 2014, after a two-month period of gathering routes for testing the app and the online platform

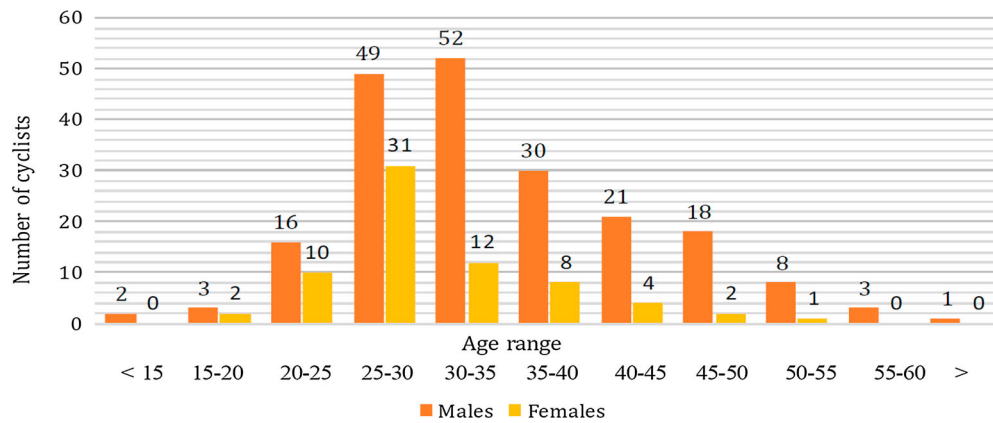


Figure 2. Cyclists according to age and gender.

performances. The initiative collected 37,345 km of cycle routes obtained from 3970 journeys. From them, 327 were gathered through the ‘Design your route’ map, and the rest are GPS tracks collected through the online, with 307 participants in total. The proportion of males and females in this sample was 72–28%, respectively, figures that correspond well to existing local surveys (DOYMO, 2011; Monzon de Cáceres, Rondinella, & Muñoz López, 2011). Figure 2 illustrates the gender proportion according to age.

The data obtained from the routes revealed differences in average speed, distance and travel time, according to the purpose of the journey. Table 1 shows the summary statistics regarding this.

The map showing all the routes together yields clear mobility patterns to the trained eye. For example, the business districts spread along the Castellana axis and the employment associated with it explain the high volume of commuter cyclists; journeys around the University Campus may include trips with mixed purposes such as leisure, sport, commuting and study; other areas such as the *Casa de Campo* park, the *Madrid Río* riverside park or the *Cycling Belt* present mainly leisure and sport journeys. A surprising finding when exploring the map is the fact that streets with high level of motor traffic are used by a significant number of cyclists. Past surveys report that intensive traffic is

one of the most significant barriers to cycling, especially for non-cyclists considering adopting cycling (Monzon de Cáceres et al., 2011). Finally, at a neighbourhood scale, some other interesting patterns can be identified; for example, the influence of the slope in hilly areas of the city, evidenced by the use of different streets when going up or down on similar routes.

2.4.2. Bike messengers results

Bike messengers’ routes were collected from November 2013 to September 2014, though the companies participated in different moments throughout this period of time. A total of 2052 routes were gathered from four different companies, providing 10,777 cycled kilometres. The total number of cyclists participating in the initiative was 23. After a cleaning process some routes were discarded (due to other possible purposes rather than couriership) and finally the route sample we analysed and visualized was composed of 1722 routes and 9143 km. Bikers’ socio-demographic data were not provided by the companies, though their profiles were similar: all were male and aged between 18 and 42 years.

Three different types of bikes were used by the messengers. Depending on the volume and weight of the material to deliver, apart from *casual bikes*, they rode *bullit cargo bikes* (or freight bikes) and *cargo trike bikes* (or freight tricycles), though the sample gathered includes very few of the latter. Some of the bullit cargo bikes and all the cargo trike bikes featured electric assistance.

The resulting map illustrates different mobility patterns compared to the ones obtained from casual bikers. The map illustrates that the main streets of the city, often those presenting highest values of vehicle traffic density, showed also the maximum cycle flow values, evidencing that bike messengers are more used and less afraid of coping with vehicles. The video visualization also evidences the different flow patterns over the course of the day, almost complementary. Casual cyclists’ performance shows the classical

Table 1. Route statistics according to the purpose of the journey.

Purpose of the journey	Routes (%)	Routes ^a (%)	Speed Av. (km/h)	Time (min) average	Distance (m) average
Commuting	31.11	42.19	15.82	24.52	5889
Leisure	17.17	23.28	15.15	23.94	5705
Sport	5.72	7.76	16.19	80.81	21,002
Shopping	6.30	8.55	14.66	22.29	5648
Management/ other	5.51	7.47	15.18	17.07	4231
Study	7.93	10.76	14.82	21.12	5201
Unknown	26.26	–	14.28	28.30	6638
Total/mean over total	100.00	100.00	15.42	31.64	7947

^aRoutes over total number with known purpose.

Table 2. Cycling statistics according to the type of bike of the messengers.

Type of bike	Routes (Uds.)	Speed Av.(km/h)	Gradient Av. (m)	Time (min) average	Distance (m) average
Normal bike	1553	19.6	95.8	30.49	5245
Bullit bike	131	19.7	63.7	11.26	3061
Cargo trike	37	11.4	134.1	14.85	2494

two peaks, early in the morning and then in the evening, and bike messengers' activity is more distributed throughout the morning and afternoon.

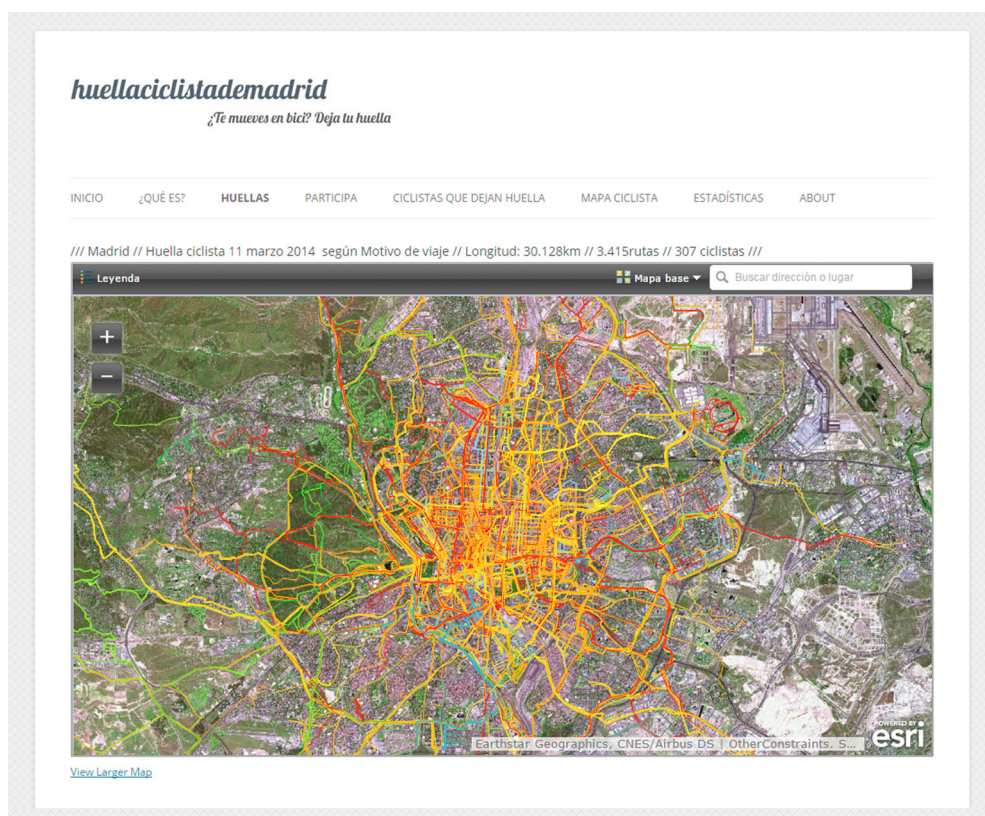
Finally, the analysis of the data derived from the GPS tracks revealed some interesting and also unexpected findings on bike messengers' behaviour. Though it is not the objective of this paper to describe them in detail, some interesting outcomes can be highlighted. It was expected that the average speed of messengers riding casual bikes (19.6 km/h) was higher than those of casual cyclists (15.42 km/h), but we found it surprising that the average speed of messengers riding bullit cargo bikes was revealed to be similar (19.7 km/h) to that of messengers riding casual bikes. In this particular case, this finding can be due to the electric assistance that most of the bullit cargo bikes feature, and the way it helps messengers in a hilly city like Madrid. Though they are also electrically assisted, the average speed of cargo trike bikes was notably lower than that of the other ones (11.4 km/h). Other

variables, such as the average distance or the height gradient of the journeys, showed also clear differences. Table 2 illustrates some basic statistics on bike messengers' mobility according to the type of the bike used.

3. The online maps

The *Madrid Cycle Track* web platform (www.huellaciclistademadrid.es) hosts different online maps aimed at illustrating both the casual cyclists' and the bike messengers' routes, and their evolution over time. All the online maps have been designed using the *ArcGIS Online* platform. They are finally embedded in different pages of the website (a *WordPress* blog) using *iframes*. In order to better configure the presentation of these maps within the website, we have used the *Web Maps for WordPress* and the *iframe* plugins.

The use of online maps offers many advantages. Because of the different functionalities they provide, they are more dynamic, more complete and easier to explore than conventional printed or digital maps. It is possible to change the extent and the scale of the map, so that we can have an idea of the global cyclist track (Figure 3) as well as to explore the cyclist flow in specific streets. We can select different base maps (provided by ArcGIS Online or other Web Maps Services) or search for specific locations. We also have access to information regarding the routes and the cyclists behind them. By selecting any track, a pop-up window emerges (Figure 4) showing different data

**Figure 3.** Screenshot of the online map illustrating casual cyclists' mobility.

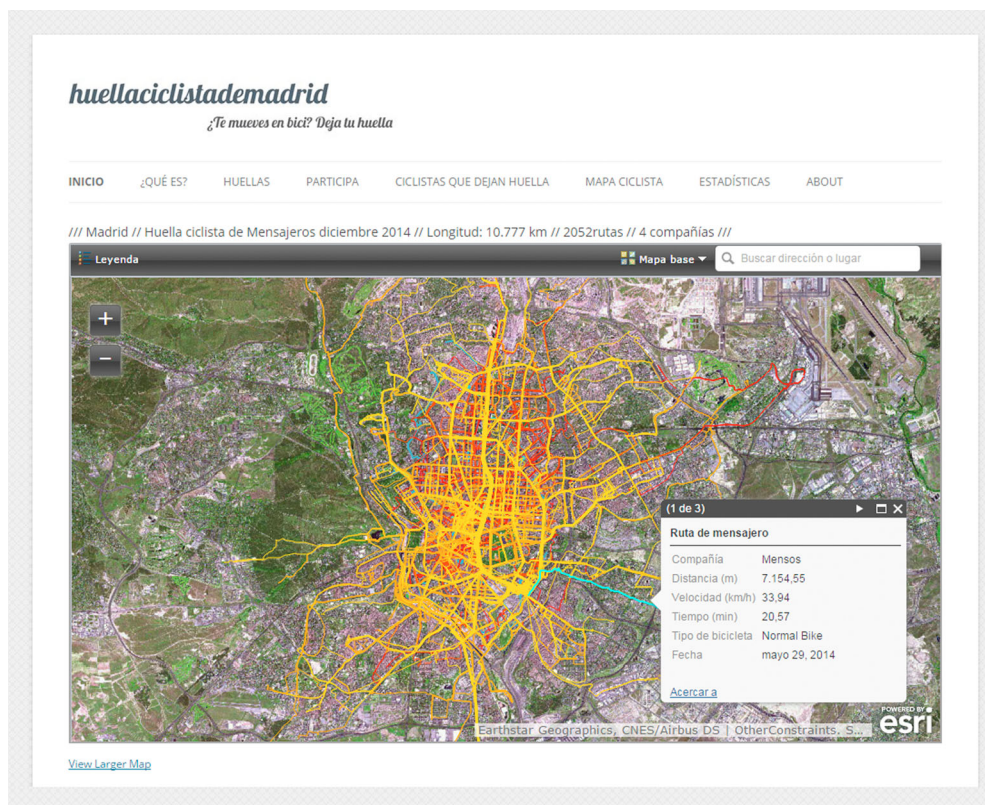


Figure 4. Screenshot of the online map illustrating bike messengers' mobility and a pop-up window with information about the selected route.

such as the name (username), age and gender of the cyclists, or the purpose of the journey, distance travelled, average speed, time, gradient, etc. These functionalities made the map attractive not only for the cyclist community participating in the project, but also for other people interested in exploring bike mobility in Madrid.

Finally, the initiative was released to people not owning a smartphone through the 'Design your route map' (Figure 5), another online map opened to public edition. Volunteers could easily design their own cyclist route on the map, using the base maps and the zoom for more accuracy, and once finished, they could introduce some personal information (username, age and gender) as well as some other information regarding the route (purpose, frequency, safety, etc.). This map was also designed using the ArcGIS Online platform. This map is accessible at the website, through the label *Participa/Dibuja tu huella* in the Menu bar.

4. The map

The **Main Map canvas** illustrates both the casual cyclists' and the bike messengers' collected routes through four different maps. The first map represents casual cyclist mobility on a map at a metropolitan scale. Routes are symbolized according to the purpose of the journey, distinguishing between work-commuting, study, shopping, leisure, sport and others, so that it

is possible to visualize not only overall cyclist flow but also the spatial patterns that emerge regarding the different purposes of cyclist journeys. A second map zooms into a central urban area, showing in detail the diverse level of cyclist flow through the different streets. The third map illustrates bike messenger mobility at the same metropolitan scale and extent used in the first map, so that it not only represents the general cyclist flow but also makes possible the comparison between the two different mobilities. In this case, routes are symbolized according to the bike messengers company. The map revealed some differences, such as not only the extent of the global cycle track, but also others that became clearer in the fourth map that zooms into another central urban area. The visualization of the tracks evidenced a stronger preference for riding in the main streets even where they have the highest motor traffic flow.

The maps represent the routes collected from 327 GPS tracks and the routes designed by cyclists through the 'Design your route' online map. In order to represent cyclist flow as a collection of different routes, these track lines were deliberately not matched to any street network layer (Figure 6). Finally, the routes are displayed over a satellite image, a GeoEye orthophoto obtained by using a web map service with ArcGIS 10.2. Different Photoshop filters were applied to the orthophoto to make it more homogeneous, to reduce contrast without losing the detail an orthophoto brings compared to base maps and to increase the contrast

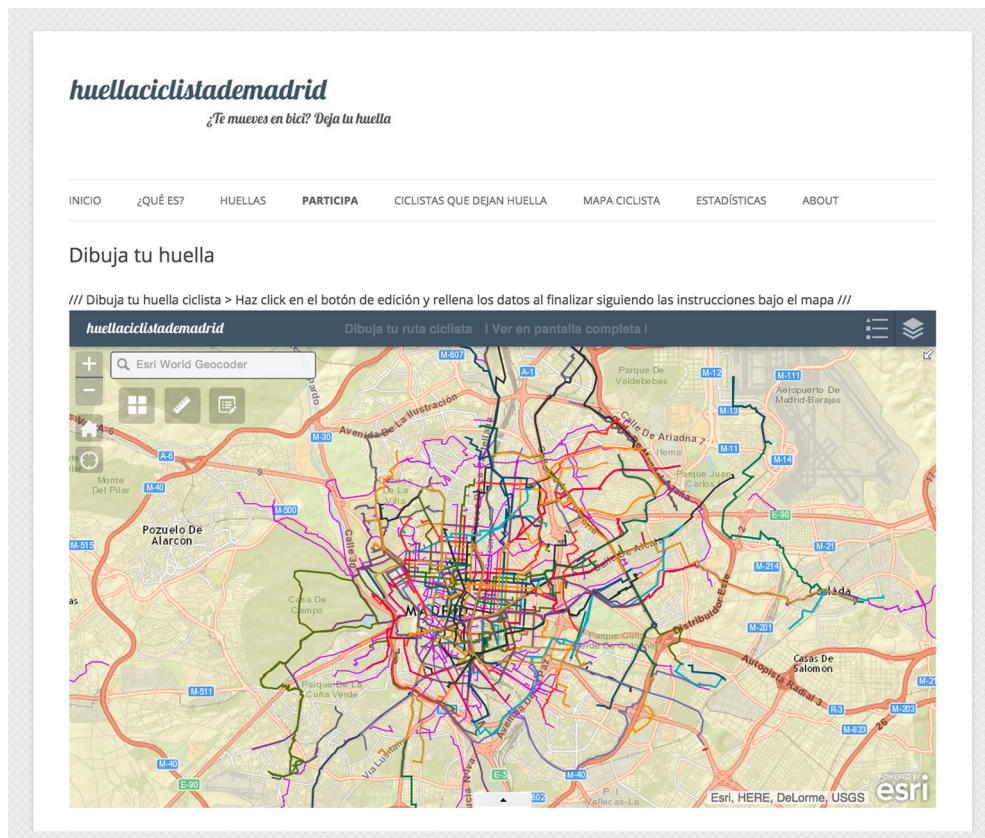


Figure 5. Screenshot of the 'Design your route' online map.

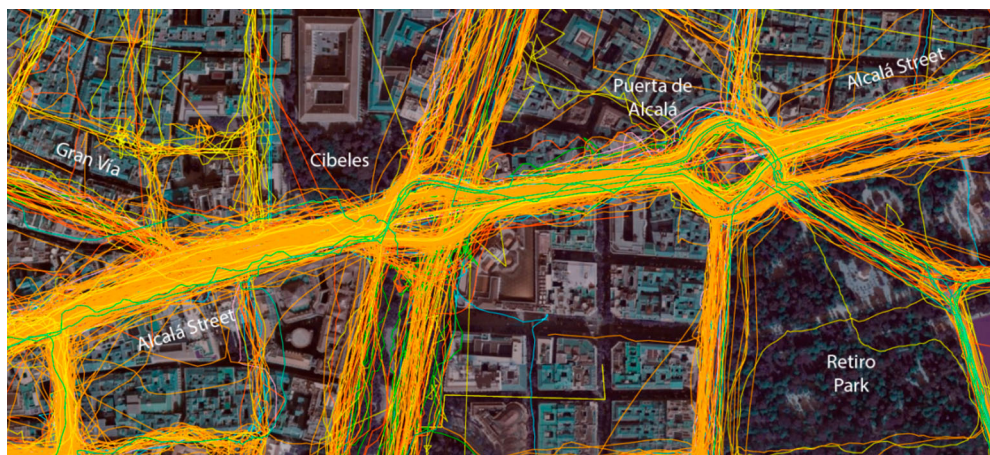


Figure 6. Visualization of casual cyclists' routes.

of the displayed routes, allowing an accurate but a clear visual exploration of the map at the same time. Administrative or political boundaries (in the case of Madrid not at all related to the extent of the urban area) were intentionally avoided in order to highlight the natural, irregular and progressively diffuse boundaries of the cycle track.

5. Dynamic visualizations

The online visualization animates the activity of both casual users and bike messengers, shown according to time of day, but collapsed from multiple days

(including several journeys by some users) onto one day, to illustrate routes and activity as they vary by time of day. In doing this, we have combined journeys from weekdays and weekends, special events and bank holidays, and journeys taking place in different days and weeks – all of which might have different characters due to different reasons for journeys, weather, seasons and traffic.

The visualization was produced using the Processing programming language (<http://processing.org>) using the code written for the purpose (<https://github.com/martinaustwick/GPS-vis>). The journey data are stored in a MySQL database in two separate

tables (one each for couriers and casual users); each table contains a series of rows which has a user ID, location and timestamp associated with that location.

In each frame, a query is sent to the couriers table, requesting all data points which were recorded less than 20 seconds after the current timestamp. These points are drawn on the screen with two increasingly large and transparent ellipses (8 and 16 pixels) drawn at the same location. This is a simple method to produce a 'heatmap' effect when multiple data points exist in close proximity at the same or similar timestamps, or when the same locations were recorded at the same time on consecutive days. This process is then repeated for the casual users, but the colour is changed to distinguish these two groups.

In between frames, a partially transparent version of the underlying map is redrawn, meaning that the location of points in previous timestamps remains partially visible, creating the illusion of a continuous path. By decreasing transparency (increasing alpha value), those previous values become more strongly obscured, emphasizing the 'current' position of cyclists; by increasing transparency (reducing alpha), prior paths are more obvious, at the expense of the most current data. In each frame, a .jpg image is captured, creating some 3150 images (17.5 h at 3 images per minute), which when assembled at 30 frames/second results in a movie of under 2 min.

6. Conclusions

The maps presented in this paper visualize the distribution of cyclist flow for the first time in the study area. This visualization reveals mobility patterns regarding the use of bikes for different purposes and disaggregated by different socio-demographic characteristics, allowing us to understand better bike mobility trends and cyclist behaviour. But the maps have played a crucial role behind the visual exploration and the analysis of the outputs. The creation of online maps was central in the design of the initiative. Online maps were dynamic; they represented the evolution of the collective track over time and let volunteers to visualize their contribution. Furthermore, cyclists were also able to design their routes on the map, so that they became not only a representation tool but also an instrument for capturing new data and engaging our community of cyclists. Maps play a central role in innovative participatory projects that bring new possibilities for collecting new data and allowing communities affected by planning changes to directly contribute to those processes. *Madrid Cycle Tracks* has demonstrated new ways to engage community stakeholders as active citizen scientists in helping to shape their city infrastructure, and demonstrated the value of

interactive mapmaking and visualization in building and maintaining these communities.

7. Software

ArcGIS 10.2 was used to process the GPS tracks, to associate the corresponding travel and socio-demographic information and to create the preliminary maps. The online maps were designed and published using *ArcGIS Online* platform. *Madrid Cycle Track* online platform is a *WordPress* blog that integrates the online maps by using *Web Maps for WordPress* and the *iframe* plugins. *Adobe Photoshop CS6* was used to apply some filters to the satellite orthophoto and *Adobe Illustrator CS6* to produce the final map. The visualization was produced using the *Processing* programming language (<http://processing.org>) using *MySQL* and associated Java connectors and the video was edited with *Windows Movie Maker*.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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